(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 756 373 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
13.09.2000 Bulletin 2000/37

(51) Int Cl.7: **H02P 6/16**, H02P 7/05

(21) Application number: **96304916.8**

(22) Date of filing: **03.07.1996**

(54) Control of a switched reluctance machine

Regelung einer geschalteten Reluktanzmaschine

Régulation d'une maschine à réluctance commuté

(84) Designated Contracting States:
BE DE ES FR GB IT NL SE

(30) Priority: **25.07.1995 GB 9515239**
19.03.1996 GB 9605724

(43) Date of publication of application:
29.01.1997 Bulletin 1997/05

(73) Proprietor: **SWITCHED RELUCTANCE DRIVES LIMITED**
Harrogate, North Yorkshire HG3 1PR (GB)

(72) Inventors:
- **Turner, Michael James**
  Leeds, LS36 3AY (GB)
- **Brown, Geoffrey Thomas**
  North Yorkshire, Y08 7RE, (GB)
- **Avet, Pol Remi**
  b-8570 Anzegem (BE)

(74) Representative: **Hale, Peter et al**
Kilburn & Strode
20 Red Lion Street
London WC1R 4PJ (GB)

(56) References cited:
EP-A- 0 239 026 **EP-A- 0 273 052**
WO-A-94/01919

- **PESC'92, vol. 2, 29 June 1992 - 3 July 1992, TOLEDO SP, pages 839-843, XP000369103 D W J PULLE ET AL: "A NEW MAGNETORESISTIVE BASED SENSOR FOR SWITCHED RELUCTANCE DRIVES"**

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

Printed by Jouve, 75001 PARIS (FR)

Description

[0001] The present invention generally relates to a controller for and a method of controlling a switched reluctance machine using signals received from a position encoder. More particularly, the present invention relates to a phase energization controller and method for controlling a switched reluctance machine using normalization circuitry and signals from a position encoder to give the angular position of the rotor of the machine.

[0002] The switched reluctance machine is a simple electric machine with no electrical conductors or permanent magnets on the rotating part and only simple, switched coils, often carrying only unidirectional currents, on the stator. This attractive combination of a simple machine, coupled with the rapidly evolving capabilities and falling costs of power-electronic switches and control electronics has led to the continued development of switched reluctance drives.

[0003] Figure 1 shows the principal components of a switched reluctance drive system 10. The input power supply 12 can be either a battery or rectified and filtered mains. The DC voltage provided by power supply 12 is switched across the phase windings of the machine 14 by the power converter 16 under the control of the electronic control unit 18. The switching must be correctly synchronized to the angle of rotation of the rotor for proper operation of the drive 10. As such, a simple rotor position encoder 20 is typically mounted on the machine shaft 22 to supply position signals to the controller 18 for determining the absolute angular position of the rotor. The encoder 20 can also be used to generate a speed feedback signal in the controller 18. Figure 1 shows this being utilized to give closed-loop speed control.

[0004] Figure 2 shows the elements of a typical four-phase switched reluctance machine 14. The machine 14 has eight salient poles 26a-h on the stator 28 and six poles 30a-f on the rotor 32. Each stator pole 26a-h carries a simple exciting coil 34a-h. Opposite coils 34a and 34e, 34b and 34f, 34c and 34g, and 34d and 34h are connected to form the north/south pole pairs for the four "phases." Only one phase circuit 36 is shown for the opposite coils 34a and 34e. The opposite coils 34a and 34e are excited from a dc supply 38 through two switches or transistors (S1 and S2), and two diodes (D1 and D2) allow energy to return to the supply 38. Other switching circuits are well known in the art.

[0005] If it is desired to operate the machine as a motor, torque is developed in the machine 14 by the tendency for the magnetic circuit to adopt a configuration of minimum reluctance, i.e., for an opposing pair of rotor poles 30a and 30d, 30b and 30e, and 30c and 30f to be pulled into alignment with an excited pair of stator poles 26a-h, maximizing the inductance of the exciting coils 34a-h . By switching the phases in the appropriate sequence, the rotor 32 will continuously rotate in either direction so that torque is developed continuously in the appropriate direction. Moreover, the larger the current supplied to the coils 34a-h, the greater the torque. Conversely, if it is desired to operate the machine as a generator, the coils are excited as the motor poles move away from the stator poles. Power is then transferred from the shaft of the machine to the electrical supply.

[0006] Figure 3 shows a rotor pole 41 approaching a stator pole 39 according to arrow 35 for the switched reluctance machine 14 of Figure 2. Figure 4 shows the phase circuit 47 for opposite coils 40 as partially depicted in Figure 3. As the rotor pole 41 approaches the stator pole 39, an energization cycle commences for the phase associated with stator pole 39. When leading edge of the rotor pole 41 reaches position 36, represented by absolute rotor angle $\theta 1$ ("on angle"), the phase transistors 44 are turned on, and the DC supply 42 is applied to the opposite coils 40, causing flux to build up. Consequently, the stator pole 39 attracts the rotor pole 41, thereby producing torque. When the rotor pole 41 reaches an absolute rotor position 37, represented by absolute rotor angle $\theta 2$ ("freewheel angle"), only one transistor 44 is turned off. This causes the current to "freewheel" around the other transistor 44 and leads to an approximately constant-flux condition. When the rotor pole 41 reaches absolute rotor position 38, represented by absolute rotor angle $\theta 3$ ("off angle"), both phase transistors 44 are held in the off state, and diodes 46 conduct, placing a voltage of reverse polarity across the winding and causing flux to decay to zero.

[0007] The on, freewheel, and off positions discussed above represent typical commutation points in the energization cycle for each phase of a switched reluctance machine. These three angles are controlled by the controller 18 to control the torque. The relationship between the angles and the torque is a nonlinear function of torque and speed. The controller 18 may interpolate from a look-up table of measured settings to obtain and update the proper commutation points for each phase of the switched reluctance machine.

[0008] Previous switched reluctance systems used a simple angular position sensor to control the energization of the motor phases. Typically, the sensor gives one pulse per phase for each energization cycle of the motor. The timing markers derived from the sensor are interpolated electronically to obtain adequate resolution. The advantage of this system is the low sensor cost. However, a substantial disadvantage exists with respect to the lack of information provided when running at slow speeds or high acceleration rates.

[0009] Absolute position encoders (e.g., resolvers, optical encoders) have been widely used in high performance drive systems for many years, particularly for position control systems. Absolute position encoders give angular resolution sufficient to remove the need for interpolation of angles, but, especially for higher resolution encoders, the absolute position encoders require more hardware, more software, or both to make adequate comparisons between the absolute rotor position and the required commutation points.

[0010] For the switched reluctance drive of Figure 2, each phase undergoes six energization cycles per rotor revolution, one for each rotor pole. Since each energization cycle has three commutation positions (on, off, and freewheel), each phase requires eighteen comparisons between these required positions and the actual rotor position. For four-phase machine, this requires a total of seventy-two such comparisons. Such an arrangement would require seventy-two sets of, e.g., the circuitry of Figure 5 which uses a twelve-bit resolver word. Figure 5 includes a twelve-bit latch 49 storing a predetermined absolute rotor position, and a twelve-bit comparator 50 for comparing the predetermined absolute rotor position with the high resolution, absolute rotor position from the position encoder or resolver 48. These techniques are standard and are well known by those skilled in the art. Other implementations would be possible.

[0011] EP-A-0273052 discloses a device for detecting the position of a rotor in a motor. An absolute position detector is coupled to the rotor shaft. The absolute position code signal is converted into a rotor position synchronisation signal for each motor control cycle.

[0012] It is an object of the invention to provide a method and circuitry for more efficiently and accurately detecting the various commutation points for the phases of a switched reluctance machine acting as a motor or a generator.

[0013] The present invention is defined in the accompanying independent claims 1, 11. Preferred features are recited in the dependent claims.

[0014] The present invention uses an absolute position encoder to directly determine the absolute rotor positions which define the commutation positions for a switched reluctance machine functioning as a motor or a generator.

[0015] Other aspects and advantages of the present invention may become apparent upon reading the following detailed description of exemplary embodiments of the invention and upon reference to the drawings in which:

Figure 1 is a block diagram of the principal components of a switched reluctance drive system;

Figure 2 is a drawing of a typical four-phase switched reluctance machine with the energization circuit shown for one phase;

Figure 3 is a diagram of a rotor pole approaching a stator pole and the commutation points for the phase associated with the stator pole;

Figure 4 is a schematic diagram of the phase circuit for the phase associated with the stator pole of Figure 3;

Figure 5 is a block diagram of one of the 72 sets of comparison circuitry required for detecting the 72 absolute rotor positions representing the commutation points per rotor revolution of the four-phase machine of Figure 2;

Figures 6a and 6b show graphs of encoder output against absolute rotor angle.

Figures 7a-c show a flow chart which represents the normalization process;

Figure 8 is a block diagram of a phase energization controller using normalization circuitry of Figure 9;

Figure 9 is a block diagram embodiment of the normalization process;

Figure 10 is a block diagram of another embodiment of the flowchart of Figure 7;

Figure 11 is a block diagram embodiment of an alternate normalization process;

Figure 12 is a block diagram of a circuit which may be used to simplify the embodiment shown in Figure 11; and

Figure 13 is a block diagram of an overcurrent detector for the phase energization controller of Figure 8.

[0016] Illustrative embodiments of the invention are described below as they might be implemented using the normalization and initialization circuitry and methods to create simpler, more efficient commutation angle detection for the phases of a switched reluctance drive.

[0017] The present invention uses a normalization circuit to simplify phase calculations. The normalization circuit normalizes the absolute rotor position value by effectively adding or subtracting an offset according to the phase being considered, the part of the mechanical revolution being considered, the desired direction of torque, and the motor direction. The normalization circuit can obtain the normalized rotor position by using logical arithmetic techniques, or by storing all the offsets in a storage device.

[0018] The first stage of the normalization process is to reduce the angle comparison circuit to that of one electrical cycle, which is feasible because each electrical cycle is identical as far as the angle control system is concerned. Thus, in a machine with six electrical cycles in one mechanical cycle, the comparison circuits are reduced by a factor of six. Figure 6A shows the variation of encoder count with rotor angle. Figure 6B shows the normalised encoder count produced as a result of this stage of the process. The technique used to achieve this will be described below.

[0019] The second stage of the normalization process is to add an offset to the encoder word for each machine phase. This permits the same logic set to be used to determine the required commutation positions for the phases, provided each phase is processed in turn (*i.e.* by time division multiplexing).

[0020] The entire normalization process is represented in the flowchart of Figure 7. Operations are performed on the processed encoder value, X, and the number of encoder counts in one electrical cycle, C.

[0021] The normalizing process first limits the range of the encoder to one electrical cycle of the machine. This is accomplished at steps 52 and 53. Step 52 compares X to C to ascertain whether the processed encoder value is greater than the number of counts in an electrical cycle. If it is, repeated subtractions are performed at step 53 where the number of encoder counts in an electrical cycle, C, is subtracted from the encoder value until the processed encoder value is less than C. Simplifications of this process may occur in practical machines. For instance, in a three-phase machine with eight rotor poles there are eight electrical cycles in a mechanical cycle. Since eight is a binary power, normalization can be achieved by simply discarding the three most significant bits of the encoder word.

[0022] Next, allowance must be made for the direction of motor rotation. If this is not done, then the encoder value would decrease if the motor is rotated backwards; such an occurrence presents significant problems in determining the commutation angles. Step 54 determines whether the motor is rotating backwards. If this occurs, then the encoder count is subtracted from the count corresponding to a complete electrical cycle at step 55. The result is again normalized at steps 56 and 57 to one electrical cycle, this time by adding a cycle if the result is negative. Again, a possible simplification can be introduced in a three-phase motor since, in that case, an electrical cycle is a power of two: the reverse direction can be accommodated by a 2's complement operation, and requires only the most significant bits to be discarded to allow for underflow.

[0023] In conventional switched reluctance drives where a simple rotor position transducer is used, it is normal to allow for a generating operation by inverting the signals from the sensors of the rotor position transducer. This moves the timing points by half an electrical cycle. The flowchart of Figure 7 performs the same operations at steps 58 and 59 to permit operating the machine as a generator. The processed encoder count is then normalized to one electrical cycle at steps 60 and 61 by subtracting a complete cycle if the value is greater than C. One embodiment of this process can be simply achieved on a four-phase machine by interchanging the commutation signals for alternate phases.

[0024] At step 62 in the flowchart of Figure 7, the processed encoder value is correct for one phase, assuming the encoder is aligned with the reference phase. Hence, the value of X may be used in the angle comparison circuitry to determine the desired state of the switches in the power conversion circuit, e.g. as shown in Figure 4.

[0025] The offsets for the remaining machine phases are added at step 63. In each case the offset is added, allowance made to correct for overflow, and the resulting value of X is thus prepared for the relevant phase.

[0026] This process repeats until angles for all phases have been calculated. Steps 66 and 67 determine whether the iteration is complete or whether to loop back to step 62 to add another phase offset. When iteration is complete, a new value of X is read from the encoder and the entire process repeats.

[0027] An angle comparison circuit is used to determine the angles at which one or more of the switches are operated. A possible circuit is shown in Figure 8. The desired "on", "freewheel" and "off" angles are calculated, typically in a microprocessor, in terms of the encoder counts. These are then stored in three latches 72, 73, and 74, and updated periodically. The latch contents are compared with the normalized encoder value in digital comparators 75, 76, and 77. The outputs of comparators 75, 76, and 77 indicate whether the three reference points are exceeded, and thus the desired energization state of the transistors can be easily derived using simple gates.

[0028] The angle comparison circuit shown in Figure 8 is typically time multiplexed, so that the same logic circuit can be used for all phases of the machine. Figure 8 shows the arrangement for a four-phase motor. A free-running counter 78 produces four enable outputs in sequence, ENA, ENB, ENC, and END, one for each phase. As each phase is selected, the normalized encoder word for that phase is calculated in block 71, the comparison made by comparators 75, 76, or 77, and the three comparator outputs stored in flip-flops 79, 80, 81 or 82. There are separate flip-flops for each phase. Means must be provided for synchronizing the counter to the phase normalization circuit 71. The encoder value must not be allowed to change during calculations, and the counter period must be low enough to permit all values to settle. Several alternatives will be apparent to those skilled in the art.

[0029] The normalization process presented in the flowchart of Figure 7 and represented by block 71 of Figure 8 can be implemented in several ways. As shown in Figure 9, the simplest method is to use a non-volatile memory device 85 (*e.g.* EPROMs) to store the output words corresponding to every combination of encoder state, machine phase, motor direction, and motoring/generating condition. Such a technique is fast and simple, and the contents of the memory can be calculated using Figure 7 as the basis of the software algorithm. Figure 9 shows the implementation for a typical four-phase machine. Here, a twelve-bit encoder 86 is used to provide the low order address lines to the memory, the four-phase enables ENA, ENB, ENC, and END are encoded to provide the next two address bits, and the motor direction signal provides the fifteenth bit. The memory output is a ten-bit word representing the normalized encoder values in the range 0-683 since this is for a machine with six rotor poles. Torque direction is allowed for by swapping phase outputs, as previously described.

[0030] The memory embodiment of Figure 9 is simple and efficient when used with standard components, but is less attractive if the circuit is to be implemented in an application-specific integrated circuit (ASIC). In this case, the preferred embodiment, shown in Figure 10, is to calculate the encoder normalization steps and the overflow corrections using a digital arithmetic unit. The arrangement of Figure 10 shows an efficient arrangement, although it will be appreciated that the details of this may easily be changed by one skilled in the art. At the start of the normalization process the current encoder state is loaded into the accumulator 91 through the multiplexer 92. The add/subtract unit 93 has one input word passed from the accumulator 91, whilst the other is connected to a multiplexer 94. This arrangement gives the possibility of adding or subtracting the values 1, C, C/2, or C/(number of phases) to the value X in the accumulator. The output of the add/subtract unit 93 is routed back to the accumulator 92 through a word-wide exclusive-OR unit 95, the latter being used to selectively invert the adder word.

[0031] Inspection of the flowchart of Figure 7 shows that the arithmetic arrangement described above is capable of providing all of the arithmetic functions needed in the algorithm. The one function which is not obvious is the calculation of X=C-X. This is achieved by inverting the add/subtract unit 93 output as it is passed back to the accumulator 91 from the previous step, adding one to the accumulator contents, giving the 2's complement of the original value, then adding C.

[0032] A comparator 96 is provided to determine whether the accumulator is greater than or equal to C, and the add/subtract unit 93 has an underflow detect to see if the result of a calculation is less than zero. These two condition flags are used to control the calculation flow according to the flowchart of Figure 7.

[0033] An alternative method of normalization may provide for simplified circuits, particularly in drives where the motor direction is not expected to change. In this case, the absolute encoder state is not normally used directly. Instead, a change of state is used to increment counters, of which there is typically one per phase. Each counter is allowed to increment until it reaches the maximum count for an electrical cycle, C, when it is reset. Hence, if the counters are initialized to represent the normalized encoder state for each phase corresponding to the actual encoder state at that time, then they will subsequently track the normalized count for the phase. The system is complicated by the need to allow for direction changes and motoring/generating conditions, and it is considered a wise precaution to have periodic checks in case of tracking errors.

[0034] Figure 11 shows a typical implementation of this alternative system. Only one phase is shown on Figure 11, although the logic is simply repeated for other phases, apart from the encoder comparison circuit, of which only one is needed. The implementation shown on Figure 11 uses synchronous logic, although asynchronous circuits could easily be used.

[0035] The up/down counter 100 is a counter which has a maximum value equal to or exceeding C. It has a clock enable input which enables the counter to increment by one count for each change of state of the encoder word, a direction control signal which controls the direction of count, a parallel load input, and an input to reset the count to zero.

[0036] The system is initialized by the microprocessor 101 reading the encoder state and calculating the normalized encoder values for each phase, loading these into the phase latch 102, then forcing a parallel load of the counter 100 from the latch 102. The processor 101 then reloads the latch 102 with the normalized phase value corresponding to an encoder count of zero, but does not force a parallel load.

[0037] If the drive is operating in the forward direction, then the encoder system 103 sets the counter 100 to count up. Each edge of the least significant bit of the encoder 103 causes all of the phase counters 100 to increment. As the counter 100 reaches a count of C it resets itself. This operation is represented by block 104. Thus, the counter 100 continues to hold the normalized count for the phases. As the encoder passes through zero (normally set to the aligned position of the first phase), then all of the phase counters 100 are loaded in parallel from the latches 102. Hence, the phase counts are realigned to the absolute encoder position once per mechanical cycle.

[0038] The drive may be set to generating mode by loading the latches in parallel at an encoder offset of C/2. This involves a delay of up to one mechanical cycle before generating commences. If such a delay is not acceptable, then the microprocessor 101 can calculate the latch values for the current encoder position and force these to be loaded immediately.

[0039] A motor direction change is detected in the encoder system 103, and this causes the counter direction to change. If the motor is unidirectional, then no further action is needed. However, if the motor is to operate in either direction, then a direction change should force a processor interrupt and thus the counters can be loaded with the values appropriate to the encoder state, the direction, and the motoring/generating state of the machine.

[0040] Simplifications are possible to the arrangement of Figure 11 which reduce the amount of logic circuits needed. For a twelve-bit encoder on a four-phase motor with six rotor poles, C = 682 2/3. If the encoder pulses are passed through a multiply-by-three and divide-by-eight circuit 106 as shown in Figure 12, then the electrical cycle consists of 256 counts. The clock enable of a three bit counter 108 remains high for three successive clock signals. As a result, the three bit counter 108 counts three times for each encoder edge. At the conclusion of three edges, an output pulse will be produced at the most significant bit Q_2 of the three bit counter 108. It is thus possible to simplify Figure 11 to use a single counter 100 for all four phases, with only a small amount of decoding on the two most significant bits to modify the counter output for each phase.

[0041] In practice, the phase energization controller preferably includes an overcurrent detector and circuitry to ensure a minimum "off" time for preventing very high switching rates. Figure 13 shows an over-current detector 110 that can be utilized with the phase energization controller of the present invention. The over-current detector 110 receives a threshold current value which is input into comparator 112. The comparator 112 also receives a phase current sensor signal representing the current level through the phase. In this particular embodiment, the output of the comparator 112 is received by an AND gate 114, and the AND gate 114 also receives the commutation signal (such as an "ON" signal from the phase energization controller of FIG. 8). If the phase current exceeds the predetermined threshold level, the overcurrent detector 110 switches off the switches.

[0042] The present invention can also utilize initialization circuitry to avoid having to mechanically align the encoder with the phases of the machine. This initialization technique involves energizing one or more phases continuously to set the rotor to a known position, reading the position encoder at the known point to obtain an initialization value, and henceforth subtracting the initialization value from the encoder reading when determining rotor angles.

[0043] Thus, the phase energization controller of the present invention provides more efficient and accurate detection of the various commutation points for the phases of an switched reluctance motor. Those skilled in the art will readily recognize that these and various other modifications and changes may be made to the present invention without strictly following the exemplary applications illustrated and described herein and without departing from the scope of the present invention, which is set forth in the following claims.

Claims

1. A switched reluctance drive system comprising a rotor defining n rotor poles, a stator, at least one phase winding defining at least one phase circuit, rotor position indicator means, switch means and a machine controller for controlling actuation of the switch means, the machine having an electrical cycle angle of 360/n°, the controller comprising: a normaliser having processing means arranged to receive, from the rotor position indicator means, a rotor position signal indicative of a rotor position angle and to produce a signal indicative of a normalised rotor position angle within a normalised electrical cycle of the machine, characterised in that the controller further includes offsetting means for offsetting the normalised rotor position angle by half an electrical cycle, the offsetting means including inverter means for inverting the normalised rotor position angle, the inverter means being selectable when the machine is changed to run as one of a motor and a generator from the other of a motor and a generator.

2. A system as claimed in claim 1, in which the processing means comprise a comparator arranged to compare the rotor position signal with a signal indicative of the electrical cycle angle and means for subtracting the signal indicative of the electrical cycle angle from the rotor position signal.

3. A system as claimed in claim 2 in which the processing means further comprise means for repeatedly subtracting the signal indicative of the electrical cycle angle from the rotor position signal until the resultant signal corresponds to an angle which is less than the electrical cycle angle.

4. A system as claimed in claim 1, 2 or 3, including derivation means for deriving a digital signal indicative of the normalised rotor position angle in response to the rotor position signal.

5. A system as claimed in claim 4, in which the derivation means include a look-up means storing values of normalised rotor position angle for different rotor position signals.

6. A system as claimed in any of the claims 1 to 5, including direction indicator means for producing a signal indicative of the sense of rotation of the rotor, the processing means being arranged to subtract the rotor position signal from the signal indicative of the electrical cycle angle when the rotor is rotating in an undesired direction.

7. A system as claimed in claim 6, including means for adding the rotor position signal to the signal indicative of the electrical cycle angle when the rotor is rotating in the undesired direction and the signal indicative of the normalised rotor position angle corresponds to an angle less than zero.

8. A system as claimed in any of the claims 1 to 7 in which the machine is a multi-phase machine, the system further including means for counting the phases and means for selecting the switch means for each phase in sequence according to the incremented phase count.

9. A system as claimed in claim 4 in which the machine comprises three phases and the rotor defines eight rotor poles, the derivation means being arranged to normalize the rotor position signal by discarding the three most significant bits of the rotor position signal.

10. A system as claimed in claim 1 in which the machine comprises three phases, the inverter means being arranged to perform a 2's complement operation on a digital version of the rotor position signal.

11. A method for normalising the timing of switching in

a switched reluctance machine having a rotor defining n rotor poles, a stator and at least one phase winding defining at least one phase circuit, each phase having an electrical cycle angle of 360/n°, the method comprising:

receiving a rotor position signal indicative of a rotor position; and
producing a signal indicative of a normalised rotor position angle within a normalised electrical cycle of the machine, characterised by
offsetting the normalised rotor position angle by half an electrical cycle, the offsetting including inverting the normalised rotor position angle when the machine is changed to run from one of a motor and a generator to the other of a motor and a generator.

12. A method as claimed in claim 11, including comparing the rotor position with the electrical cycle angle and subtracting the electrical cycle angle from the rotor position.

13. A method as claimed in claim 12, including repeatedly subtracting the electrical cycle angle from the rotor position until the resultant angle is less than the electrical cycle angle.

14. A method as claimed in claim 11, 12 or 13, including deriving a digital signal indicative of a normalised rotor position angle in response to the rotor position signal.

15. A method as claimed in claim 14 in which the digital signal is derived from a look-up table storing values of normalised rotor position angles for different rotor position signals.

16. A method as claimed in any of the claims 11 to 15, including producing a signal indicative of the sense of rotation of the rotor and subtracting the rotor position from the electrical cycle angle when the rotor is rotating in an undesired direction.

17. A method as claimed in claim 16 in which the rotor position signal is added to the electrical signal angle when the rotor is rotating in the undesired direction and the normalised rotor position angle corresponds to less than zero.

18. A method as claimed in any of the claims 11 to 17, including counting the phases and selecting the switch means for each phase for actuation in sequence according to the incremented phase count.

19. A method as claimed in claim 14 for a machine comprising three phases having a rotor defining eight rotor poles, in which the rotor position signal is normalised by discarding the three most significant bits of the encoder signal.

20. A method as claimed in claim 11 for a machine comprising three phases, including inverting by performing a 2's complement operation on a digital version of the rotor position signal.

21. A method as claimed in any of claims 11 to 20, including initialising the rotor position signal to a rotor position by energising one or more phases of the machine to set the rotor to a known position, reading the rotor position signal at the known position to obtain an initialisation value and, thereafter, subtracting the initialisation value from the signal indicative of rotor position.

Patentansprüche

1. Geschaltetes Reluktanz-Antriebssystem, umfassend:
einen Rotor, der n Rotorpole definiert, einen Stator, wenigstens eine Phasenwicklung, die wenigstens eine Phasenschaltung definiert, eine Rotorpositions-Anzeigeeinrichtung, eine Schalteinrichtung und eine Maschinen-Steuereinrichtung zum Steuern des Auslösens der Schalteinrichtung, wobei die Maschine einen elektrischen Zykluswinkel von 360/n° aufweist, wobei die Steuereinrichtung umfasst: eine Normierungseinrichtung, die eine Verarbeitungseinrichtung aufweist, die angeordnet ist, um von der Rotorpositions-Anzeigeeinrichtung ein Rotorpositionssignal zu empfangen, das einen Rotorpostionswinkel anzeigt, und um ein Signal zu erzeugen, das einen normierten Rotorpositionswinkel innerhalb eines normierten elektrischen Zyklus der Maschine anzeigt, **dadurch gekennzeichnet, dass** die Steuereinrichtung ferner eine Versatzeinrichtung zum Versetzen des normierten Rotorpositionswinkels um einen halben elektrischen Zyklus umfasst, wobei die Versatzeinrichtung eine Invertiereinrichtung zum Invertieren des normierten Rotorpositionswinkels umfasst, wobei die Invertiereinrichtung wählbar ist, wenn die Maschine vom Motorbetrieb in den Generatorbetrieb oder vom Generatorbetrieb in den Motorbetrieb umgeschaltet wird.

2. System nach Anspruch 1, bei welchem die Verarbeitungseinrichtung einen Komparator umfasst, der angeordnet ist, um das Rotorpositionssignal mit einem Signal, das den elektrischen Zykluswinkel anzeigt, zu vergleichen, sowie eine Einrichtung zum Subtrahieren des Signals, das den elektrischen Zykluswinkel anzeigt, von dem Rotorpositionssignal.

3. System nach Anspruch 2, bei welchem die Verarbeitungseinrichtung ferner eine Einrichtung zum

wiederholten Subtrahieren des Signals umfasst, das den elektrischen Zykluswinkel anzeigt, von dem Rotorpositionssignal bis das resultierende Signal einem Winkel entspricht, der kleiner als der elektrische Zykluswinkel ist.

4. System nach Anspruch 1, 2 oder 3, welches eine Herleitungseinrichtung zum Herleiten eines digitalen Signals umfasst, welches den normierten Rotorpositionswinkel in Antwort auf den Rotorpositionswinkel anzeigt.

5. System nach Anspruch 4, in welchem die Herleitungseinrichtung eine look-up-Einrichtung umfasst, welche die Werte des normierten Rotorpositionswinkels für unterschiedliche Rotorpositionssignale speichert.

6. System nach einem der Ansprüche 1 bis 5, welches eine Richtungsanzeige-Vorrichtung zum Erzeugen eines Signals umfasst, welches die Drehrichtung des Rotors anzeigt, wobei die Verarbeitungseinrichtung angeordnet ist, um das Rotorpositionssignal von dem Signal zu subtrahieren, das den elektrischen Zykluswinkel anzeigt, wenn der Rotor in eine unerwünschte Richtung rotiert.

7. System nach Anspruch 6, welches eine Einrichtung zum Addieren des Rotorpositionssignals zu dem Signal umfasst, das den elektrischen Zykluswinkel anzeigt, wenn der Rotor in die unerwünschte Richtung rotiert und das Signal, das den normierten Rotorpositionswinkel anzeigt, einem Winkel kleiner Null entspricht.

8. System nach einem der Ansprüche 1 bis 7, in welchem die Maschine eine Multi-Phasen-Maschine ist, wobei das System ferner eine Einrichtung zum Zählen der Phasen und eine Einrichtung zum Auswählen der Schalteinrichtung für jede Phase der Reihe nach gemäß dem inkrementierten Phasenzähler umfasst.

9. System nach Anspruch 4, in welchem die Maschine drei Phasen umfasst und der Rotor acht Rotorpole definiert, wobei die Herleitungseinrichtung angeordnet ist, um das Rotorpositionssignal durch das Weglassen der drei signifikantesten Bits des Rotorpositionssignals zu normieren.

10. System nach Anspruch 1, in welchem die Maschine drei Phasen umfasst, wobei die Invertiereinrichtung angeordnet ist, um eine Zweier-Komplement-Operation bei einer digitalen Version des Rotorpositionssignals durchzuführen.

11. Verfahren zum Normieren der zeitlichen Abstimmung des Schaltens in einer geschalteten Reluktanzmaschine, die einen Rotor aufweist, der Rotorpole definiert, sowie einen Stator und wenigstens eine Phasenwicklung, die wenigstens eine Phasenschaltung definiert, wobei jede Phase einen elektrischen Zykluswinkel von 360/n° aufweist, wobei das Verfahren umfasst:
Empfangen eines Rotorpositionssignals, das eine Rotorposition anzeigt; und Erzeugen eines Signals, das einen normierten Rotorpositionswinkel innerhalb eines normierten elektrischen Zyklus der Maschine anzeigt, **gekennzeichnet durch** Versetzen des normierten Rotorpositionswinkels um einen halben elektrischen Zyklus, wobei das Versetzen das Invertieren des normierten Rotorpositionswinkels umfasst, wenn die Maschine vom Motorbetrieb in den Generatorbetrieb oder vom Generatorbetrieb in den Motorbetrieb umgeschaltet wird.

12. Verfahren nach Anspruch 11, welches das Vergleichen der Rotorposition mit dem elektrischen Zykluswinkel und das Subtrahieren des elektrischen Zykluswinkels von der Rotorposition umfasst.

13. Verfahren nach Anspruch 12, welches das wiederholte Subtrahieren des elektrischen Zykluswinkels von der Rotorposition umfasst, bis der resultierende Winkel kleiner als der elektrische Zykluswinkel ist.

14. Verfahren nach Anspruch 11, 12 oder 13, welches das Herleiten eines digitalen Signals umfasst, welches einen normierten Rotorpositionswinkel in Antwort auf das Rotorpositionssignal anzeigt.

15. Verfahren nach Anspruch 14, bei welchem das digitale Signal von einer look-up Tabelle hergeleitet wird, welche Werte von normierten Rotorpositionswinkeln für unterschiedliche Rotorpositionssignale speichert.

16. Verfahren nach einem der Ansprüche 11 bis 15, welches das Erzeugen eines Signals, welches die Drehrichtung des Rotors anzeigt umfasst, sowie das Subtrahieren der Rotorposition von dem elektrischen Zykluswinkel, wenn der Rotor in eine unerwünschte Richtung rotiert.

17. Verfahren nach Anspruch 16, bei welchem das Rotorpositionssignal zu dem elektrischen Signalwinkel addiert wird, wenn der Rotor in der unerwünschten Richtung rotiert und der normierte Rotorpositionswinkel kleiner Null ist.

18. Verfahren nach einem der Ansprüche 11 bis 17, welches das Zählen der Phasen und das Auswählen der Schalteinrichtung für jede Phase zum aufeinanderfolgenden Auslösen gemäß dem inkrementierten Phasenzähler umfasst.

19. Verfahren nach Anspruch 14 für eine Maschine mit drei Phasen, welche einen Rotor aufweist, der acht Rotorpole definiert, in welchem das Rotorpositionssignal durch das Weglassen der drei signifikantesten Bits des Encoder-Signals normiert wird.

20. Verfahren nach Anspruch 11 für eine Maschine, die drei Phasen umfasst, umfassend das Invertieren durch das Durchführen einer Zweier-Komplement-Operation bei einer digitalen Version des Rotorpositionssignals.

21. Verfahren nach einem der Ansprüche 11 bis 20, umfassend: Initialisieren des Rotorpositionssignals bei einer Rotorposition durch das Erregen einer oder mehrerer Phasen der Maschine, um den Rotor in eine bekannte Position zu setzen, Einlesen des Rotorpositionssignals bei der bekannten Position, um einen Initialisierungswert zu erhalten und nachfolgendes Subtrahieren des Initialisierungswertes von dem Signal, das die Rotorposition anzeigt.

Revendications

1. Système d'entraînement à réluctance commutée comprenant un rotor définissant n pôles de rotor, un stator, au moins un enroulement de phase qui définit au moins un circuit de phase, des moyens indicateurs de position du rotor, des moyens de commutation et un dispositif de régulation de la machine pour commander l'actionnement des moyens de commutation, la machine ayant un angle de cycle électrique de 360/n°, le dispositif de régulation comprenant : un normalisateur ayant un moyen de traitement agencé pour recevoir, des moyens indicateurs de position du rotor, un signal de position du rotor indicatif d'un angle de position du rotor et pour produire un signal indicatif d'un angle normalisé de position du rotor dans un cycle électrique normalisé de la machine, caractérisé en ce que le dispositif de régulation comprend en outre des moyens de décalage pour décaler l'angle normalisé de position du rotor d'un demi-cycle électrique, les moyens de décalage comprenant des moyens inverseurs pour inverser l'angle normalisé de position du rotor, les moyens inverseurs pouvant être sélectionnés lorsqu'on modifie la machine pour qu'elle passe d'un état en mode moteur ou générateur à un autre état en mode moteur ou générateur.

2. Système selon la revendication 1, dans lequel le moyen de traitement comprend un comparateur agencé pour comparer le signal de position du rotor à un signal indicatif de l'angle de cycle électrique et un moyen pour soustraire le signal indicatif de l'angle de cycle électrique du signal de position du rotor.

3. Système selon la revendication 2, dans lequel le moyen de traitement comprend en outre un moyen pour soustraire de manière répétée le signal indicatif de l'angle de cycle électrique du signal de position du rotor jusqu'à ce que le signal obtenu corresponde à un angle qui est inférieur à l'angle de cycle électrique.

4. Système selon la revendication 1, 2 ou 3, comprenant un moyen de dérivation pour obtenir un signal numérique indicatif de l'angle normalisé de position du rotor en réponse au signal de position du rotor.

5. Système selon la revendication 4, dans lequel le moyen de dérivation comprend un moyen de consultation qui stocke des valeurs de l'angle normalisé de position du rotor pour différents signaux de position de rotor.

6. Système selon l'une quelconque des revendications 1 à 5, comprenant un moyen indicateur de sens pour produire un signal indicatif du sens de rotation du rotor, le moyen de traitement étant aménagé de manière à soustraire le signal de position du rotor du signal indicatif de l'angle de cycle électrique lorsque le rotor tourne dans un sens non souhaité.

7. Système selon la revendication 6, comprenant un moyen d'addition du signal de position du rotor au signal indicatif de l'angle de cycle électrique lorsque le rotor tourne dans le sens non souhaité et que le signal indicatif de l'angle normalisé de position du rotor correspond à un angle inférieur à zéro.

8. Système selon l'une quelconque des revendications 1 à 7 dans lequel la machine est une machine multiphase, le système comprenant en outre des moyens de comptage de phases et des moyens de sélection des moyens de commutation pour chaque phase en séquence selon le comptage de phase incrémenté.

9. Système selon la revendication 4, dans lequel la machine comprend trois phases et le rotor définit huit pôles de rotor, le moyen de dérivation étant aménagé pour normaliser le signal de position du rotor en éliminant les trois bits les plus significatifs du signal de position du rotor.

10. Système selon la revendication 1, dans lequel la machine comprend trois phases, les moyens inverseurs étant aménagés pour effectuer une opération de complément de 2 sur une version numérique du signal de position du rotor.

11. Procédé de normalisation de la synchronisation de la commutation dans une machine à réluctance commutée ayant un rotor qui définit n pôles de rotor, un stator et au moins un enroulement de phase qui définit au moins un circuit de phase, chaque phase ayant un angle de cycle électrique de 360/n°, le procédé comprenant les étapes consistant :

> à recevoir un signal de position du rotor indicatif d'une position du rotor, et
> à produire un signal indicateur d'un angle normalisé de position du rotor dans un cycle électrique normalisé de la machine, caractérisé par l'étape consistant :
> à décaler l'angle normalisé de position du rotor d'un demi-cycle électrique, le décalage comprenant l'inversion de l'angle normalisé de position du rotor lorsqu'on modifie la machine pour qu'elle tourne en passant d'un état en mode moteur ou générateur à un autre état en mode moteur ou générateur.

12. Procédé selon la revendication 11, comprenant la comparaison de la position de rotor avec l'angle de cycle électrique et la soustraction de l'angle de cycle électrique de la position du rotor.

13. Procédé selon la revendication 12, comprenant la soustraction répétée de l'angle de cycle électrique de la position du rotor jusqu'à ce que l'angle obtenu soit inférieur à l'angle de cycle électrique.

14. Procédé selon la revendication 11, 12 ou 13, comprenant la dérivation d'un signal numérique indicatif d'un angle normalisé de position du rotor en réponse au signal de position du rotor.

15. Procédé selon la revendication 14, dans lequel le signal numérique est dérivé d'une table de consultation qui stocke des valeurs d'angles normalisés de position du rotor pour différents signaux de position de rotor.

16. Procédé selon l'une quelconque des revendications 11 à 15, comprenant la production d'un signal indicatif du sens de rotation du rotor et la soustraction de la position du rotor de l'angle de cycle électrique lorsque le rotor tourne dans un sens non souhaité.

17. Procédé selon la revendication 16, dans lequel le signal de position du rotor est ajouté à l'angle de signal électrique lorsque le rotor tourne dans le sens non souhaité et que l'angle normalisé de position du rotor correspond à un angle inférieur à zéro.

18. Système selon l'une quelconque des revendications 11 à 17, comprenant le comptage des phases et la sélection des moyens de commutation pour chaque phase pour un actionnement en séquence selon le comptage de phase incrémenté.

19. Procédé selon la revendication 14 pour une machine comprenant trois phases et ayant un rotor définissant huit pôles de rotor, dans lequel le signal de position du rotor est normalisé en éliminant les trois bits les plus significatifs du signal du codeur.

20. Procédé selon la revendication 11 pour une machine comprenant trois phases, comprenant une inversion en effectuant une opération de complément de 2 sur une version numérique du signal de position du rotor.

21. Procédé selon l'une quelconque des revendications 11 à 20, comprenant l'initialisation du signal de position du rotor dans une position du rotor en excitant une ou plusieurs phases de la machine pour régler le rotor dans une position connue, la lecture du signal de position du rotor dans la position connue pour obtenir une valeur d'initialisation et, ensuite, la soustraction de la valeur d'initialisation du signal indicatif de la position du rotor.

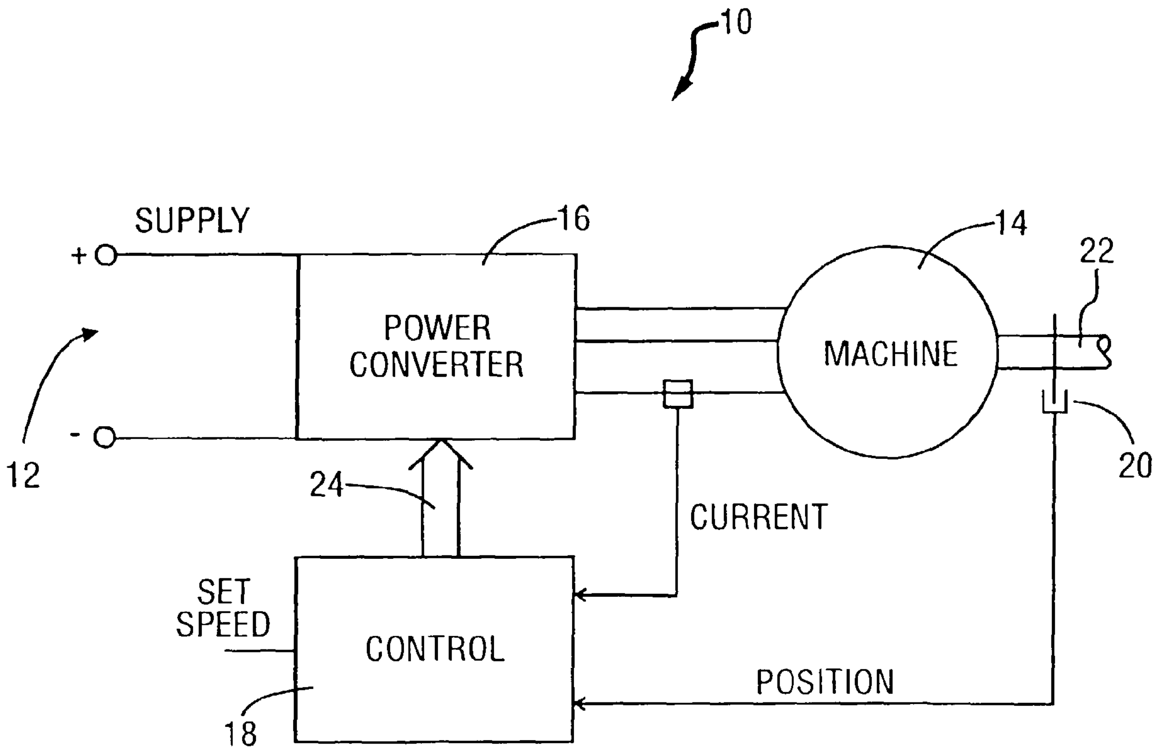
10
SUPPLY
+
-
12
16
POWER CONVERTER
14
MACHINE
22
20
24
CURRENT
SET SPEED
CONTROL
18
POSITION

FIG. 1

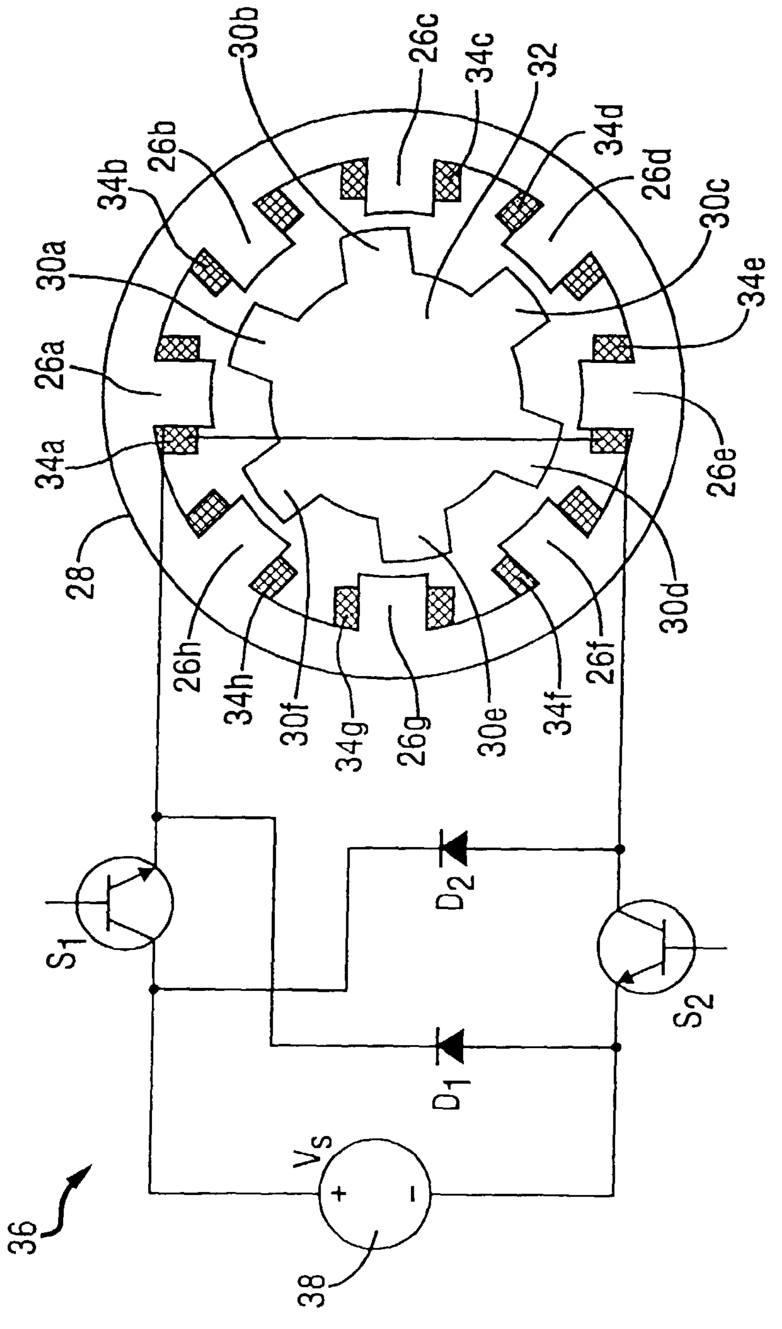

FIG. 2
(Prior Art)

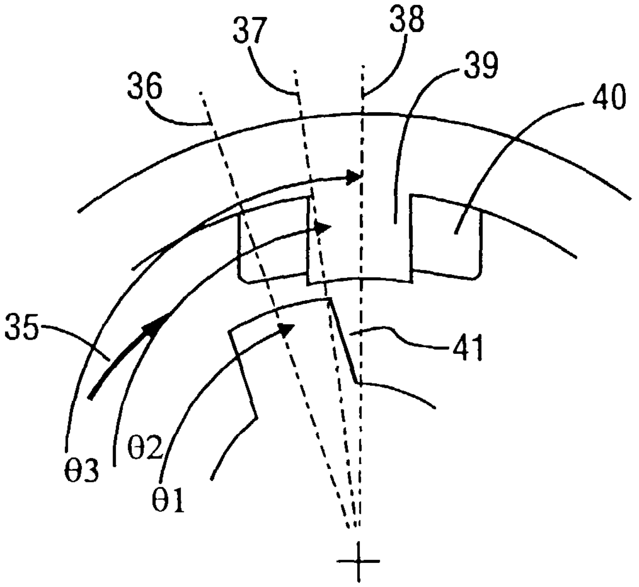

FIG. 3
(Prior Art)

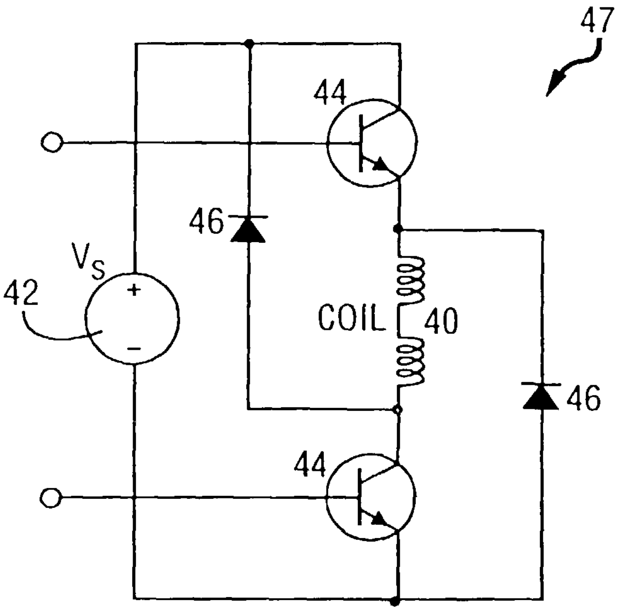

FIG. 4
(Prior Art)

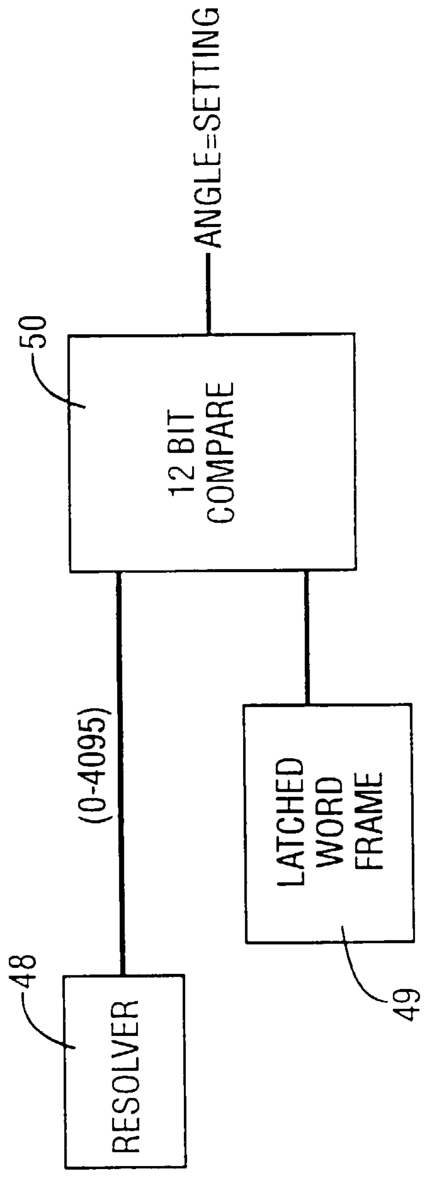

FIG. 5
(Prior Art)

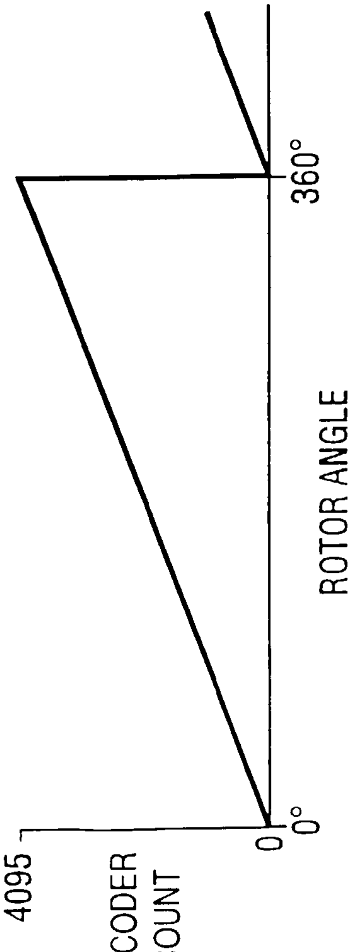
4095
ENCODER COUNT
0
0°
360°
ROTOR ANGLE

FIG. 6A

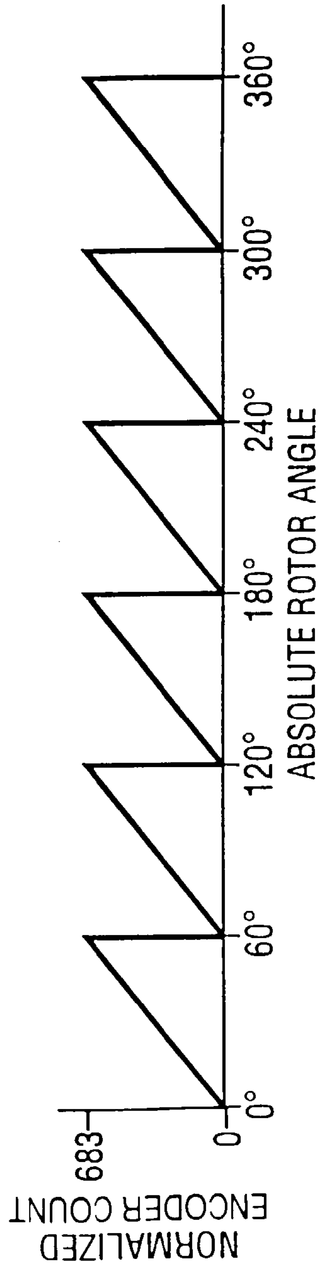
683
NORMALIZED ENCODER COUNT
0
0°
60°
120°
180°
240°
300°
360°
ABSOLUTE ROTOR ANGLE

FIG. 6B

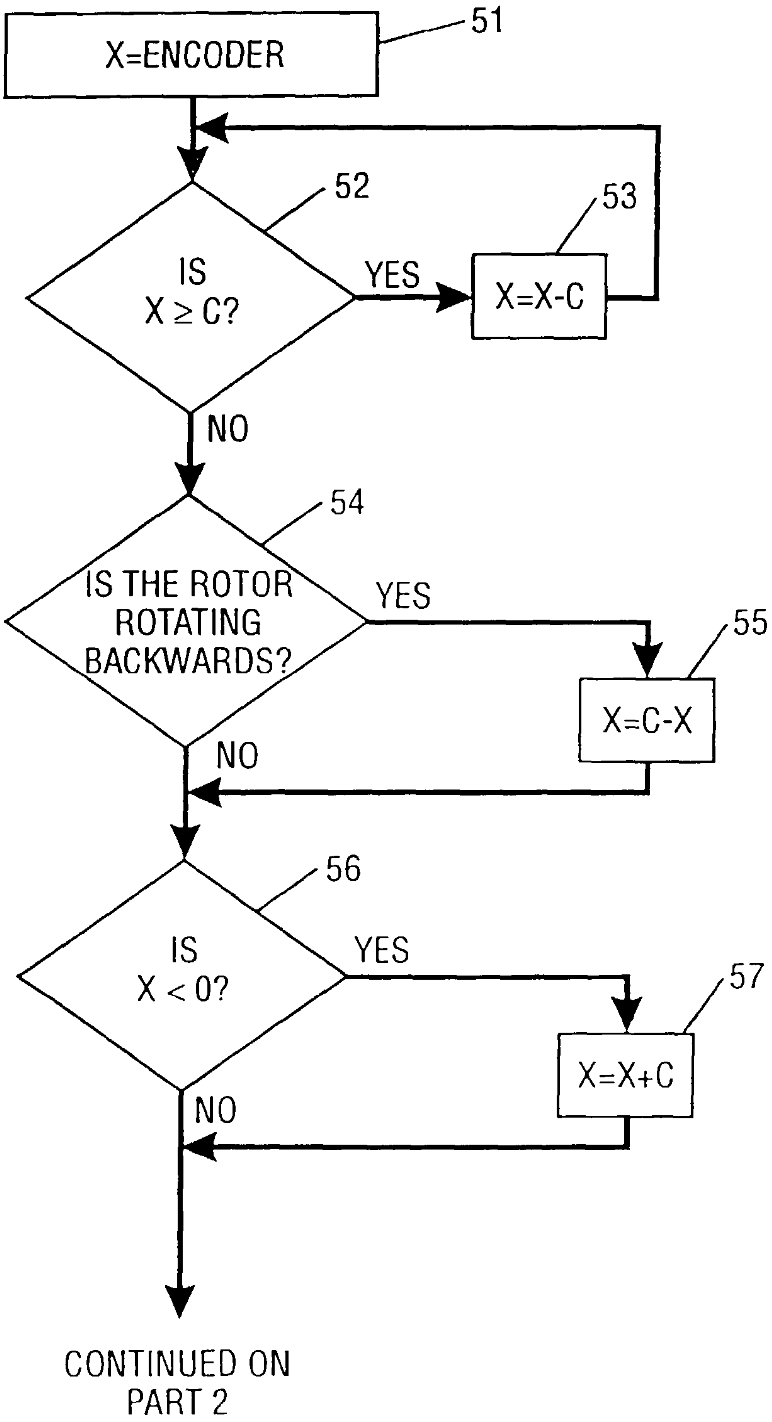
X=ENCODER
51
52
IS X ≥ C?
YES
NO
53
X=X-C
54
IS THE ROTOR ROTATING BACKWARDS?
YES
NO
55
X=C-X
56
IS X < 0?
YES
NO
57
X=X+C
CONTINUED ON PART 2

FIG. 7a

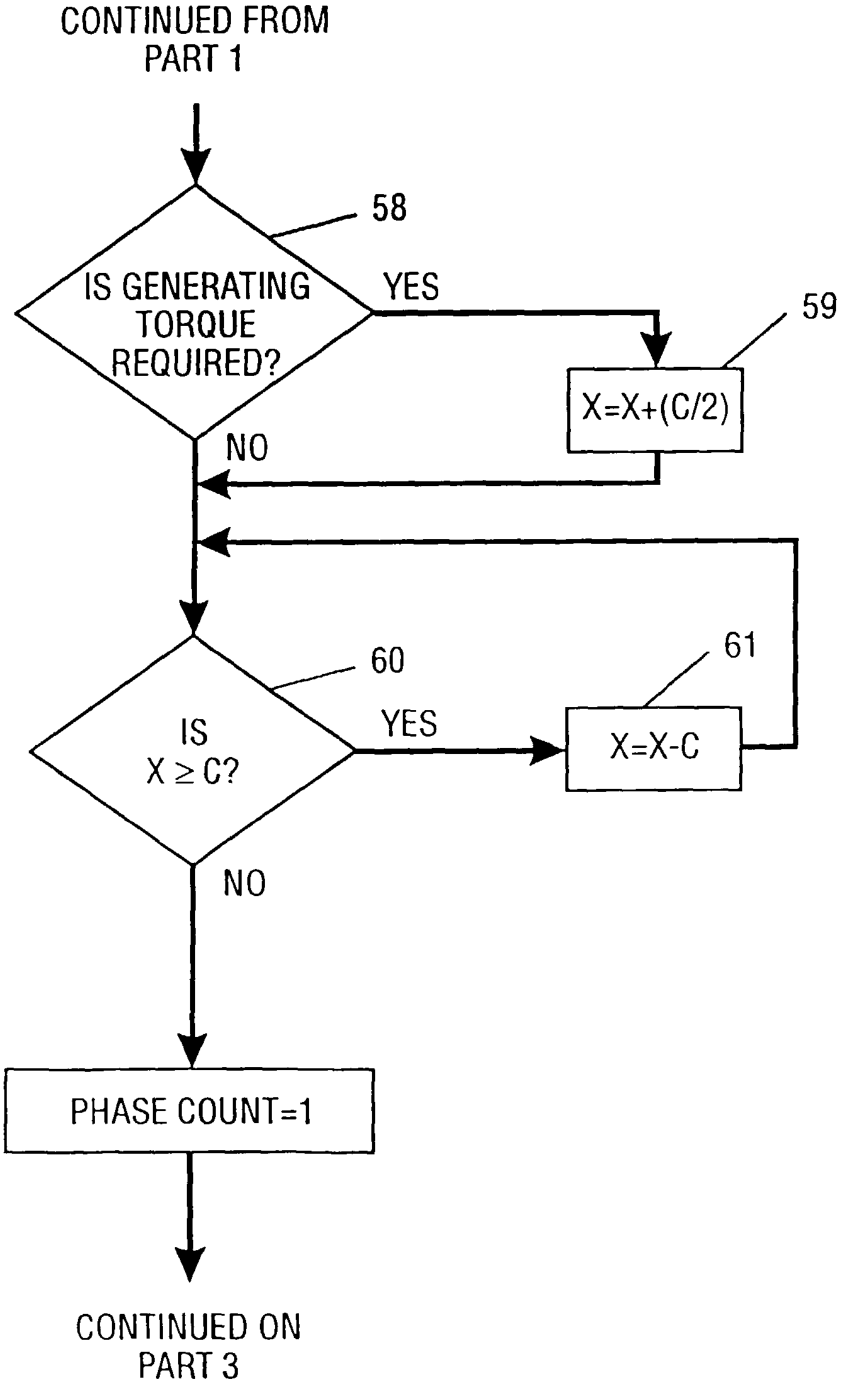
CONTINUED FROM
PART 1
58
IS GENERATING TORQUE REQUIRED?
YES
NO
59
X=X+(C/2)
60
IS X ≥ C?
YES
NO
61
X=X-C
PHASE COUNT=1
CONTINUED ON
PART 3

FIG. 7b

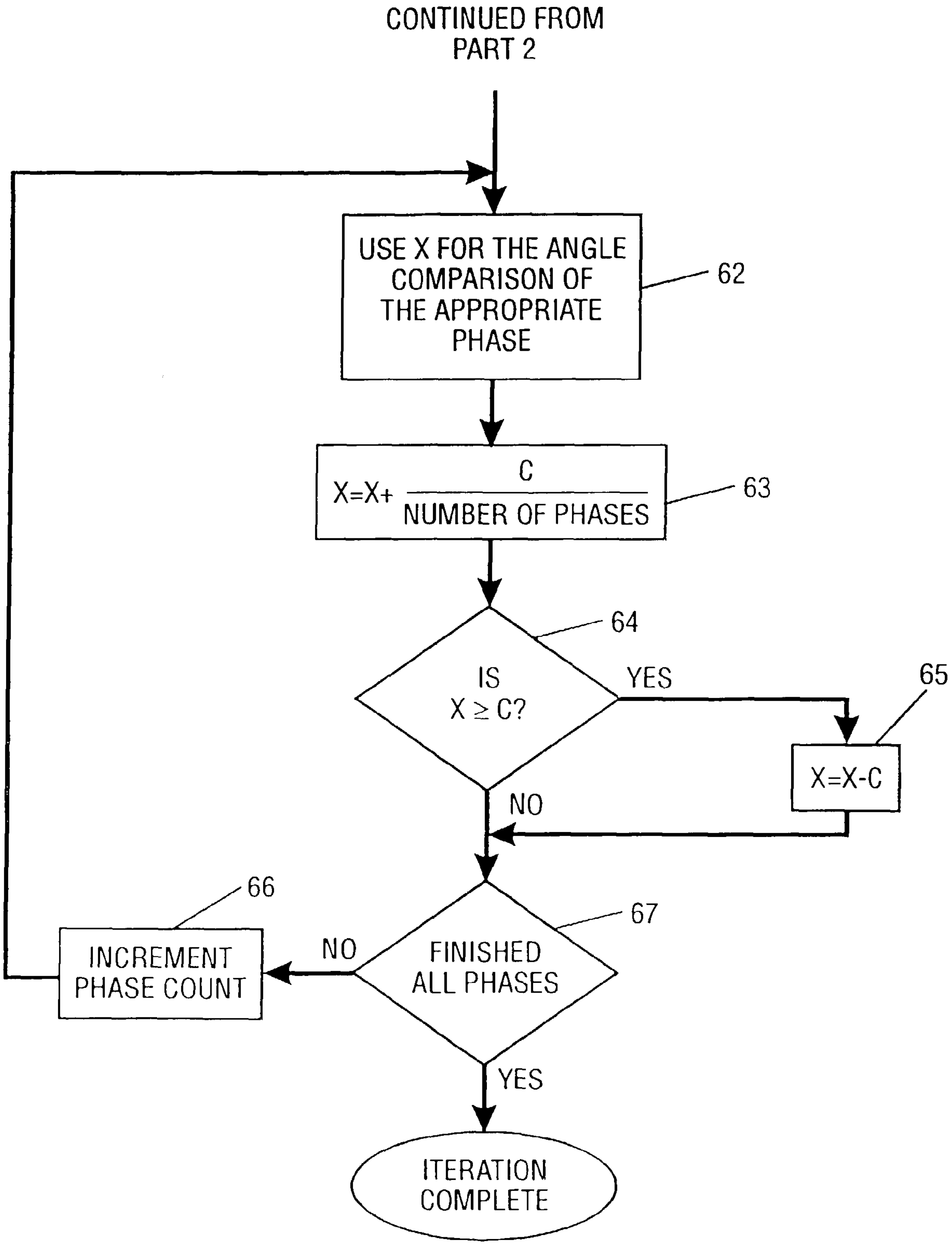
CONTINUED FROM PART 2
USE X FOR THE ANGLE COMPARISON OF THE APPROPRIATE PHASE
62
X=X+ C / NUMBER OF PHASES
63
64
IS X ≥ C?
YES
65
X=X-C
NO
66
67
INCREMENT PHASE COUNT
NO
FINISHED ALL PHASES
YES
ITERATION COMPLETE

FIG. 7c

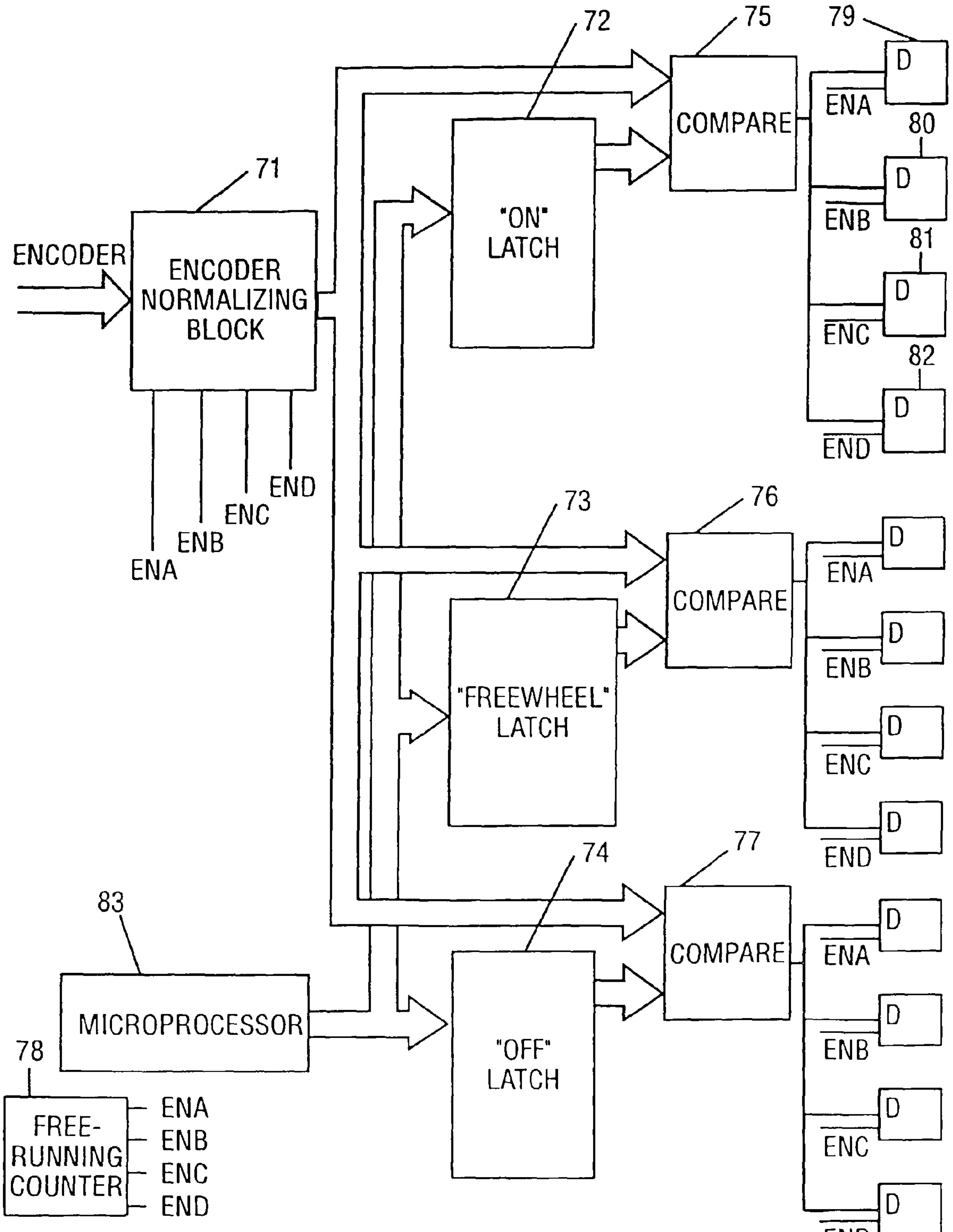
ENCODER
ENCODER NORMALIZING BLOCK
71
ENA
ENB
ENC
END
72
"ON" LATCH
73
"FREEWHEEL" LATCH
74
"OFF" LATCH
75
76
77
COMPARE
COMPARE
COMPARE
79
80
81
82
D
ENA
ENB
ENC
END
83
MICROPROCESSOR
78
FREE-RUNNING COUNTER
ENA
ENB
ENC
END

FIG. 8

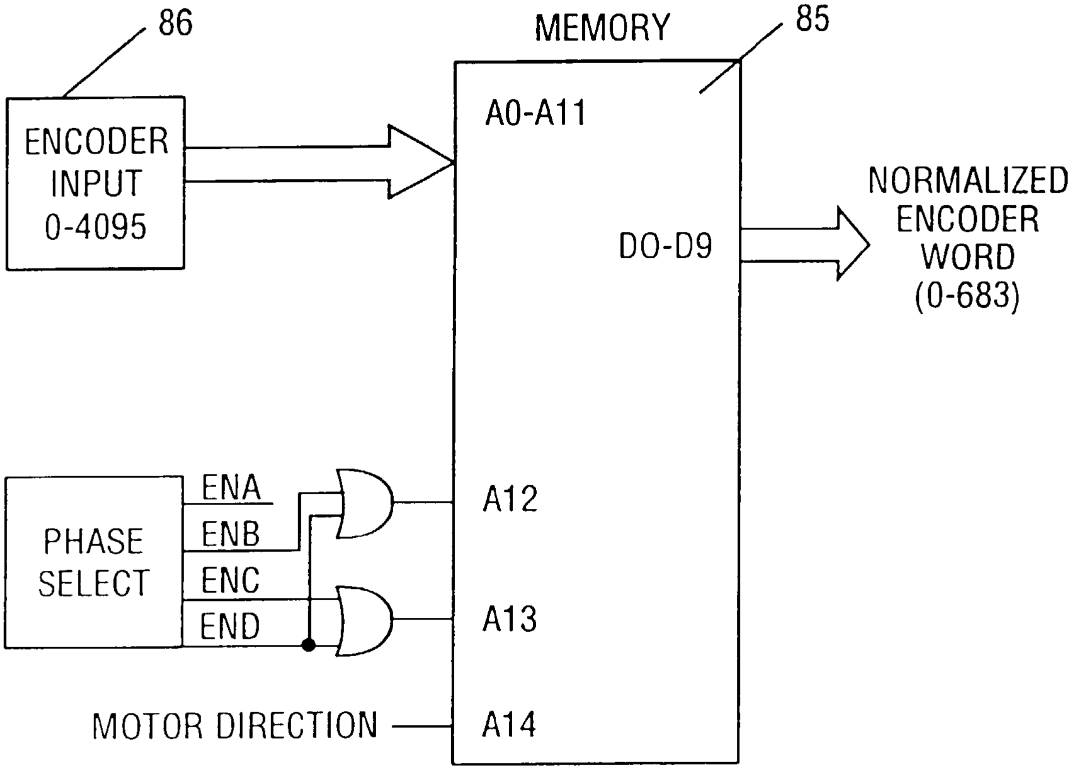
86
MEMORY
85
ENCODER
INPUT
0-4095
A0-A11
NORMALIZED
ENCODER
WORD
(0-683)
DO-D9
PHASE
SELECT
ENA
ENB
ENC
END
A12
A13
MOTOR DIRECTION
A14

FIG. 9

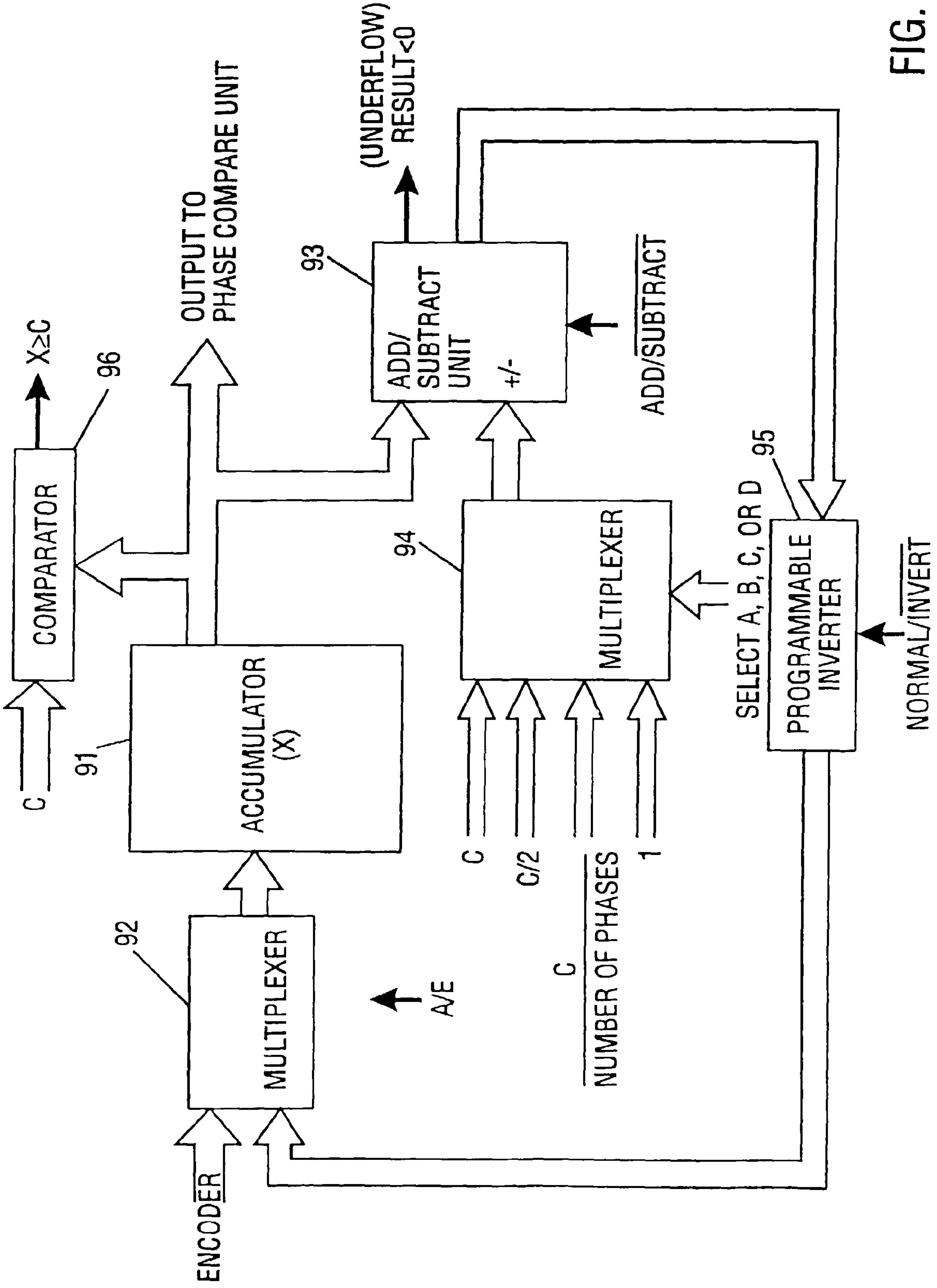
C
X≥C
96
COMPARATOR
91
ACCUMULATOR (X)
92
MULTIPLEXER
ENCODER
A/E
OUTPUT TO PHASE COMPARE UNIT
93
ADD/ SUBTRACT UNIT
+/-
(UNDERFLOW) RESULT<0
ADD/$\overline{\text{SUBTRACT}}$
94
MULTIPLEXER
C
C/2
$\frac{C}{\text{NUMBER OF PHASES}}$
1
SELECT A, B, C, OR D
95
PROGRAMMABLE INVERTER
NORMAL/$\overline{\text{INVERT}}$

FIG. 10

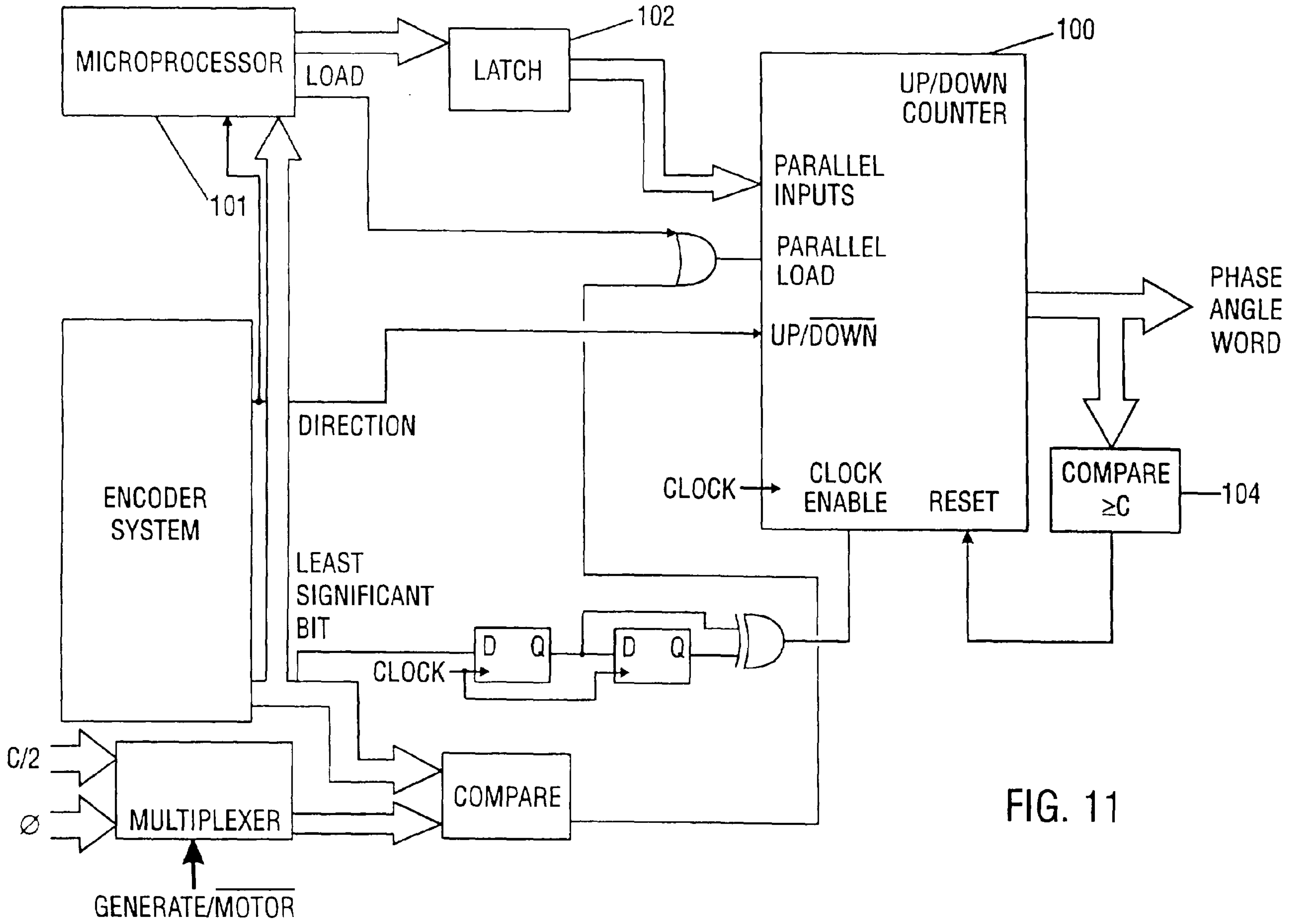
MICROPROCESSOR
LOAD
LATCH
102
100
UP/DOWN
COUNTER
PARALLEL
INPUTS
PARALLEL
LOAD
UP/$\overline{\text{DOWN}}$
101
ENCODER
SYSTEM
DIRECTION
CLOCK
CLOCK
ENABLE
RESET
PHASE
ANGLE
WORD
COMPARE
≥C
104
LEAST
SIGNIFICANT
BIT
D
Q
D
Q
CLOCK
C/2
∅
MULTIPLEXER
COMPARE
GENERATE/$\overline{\text{MOTOR}}$

FIG. 11

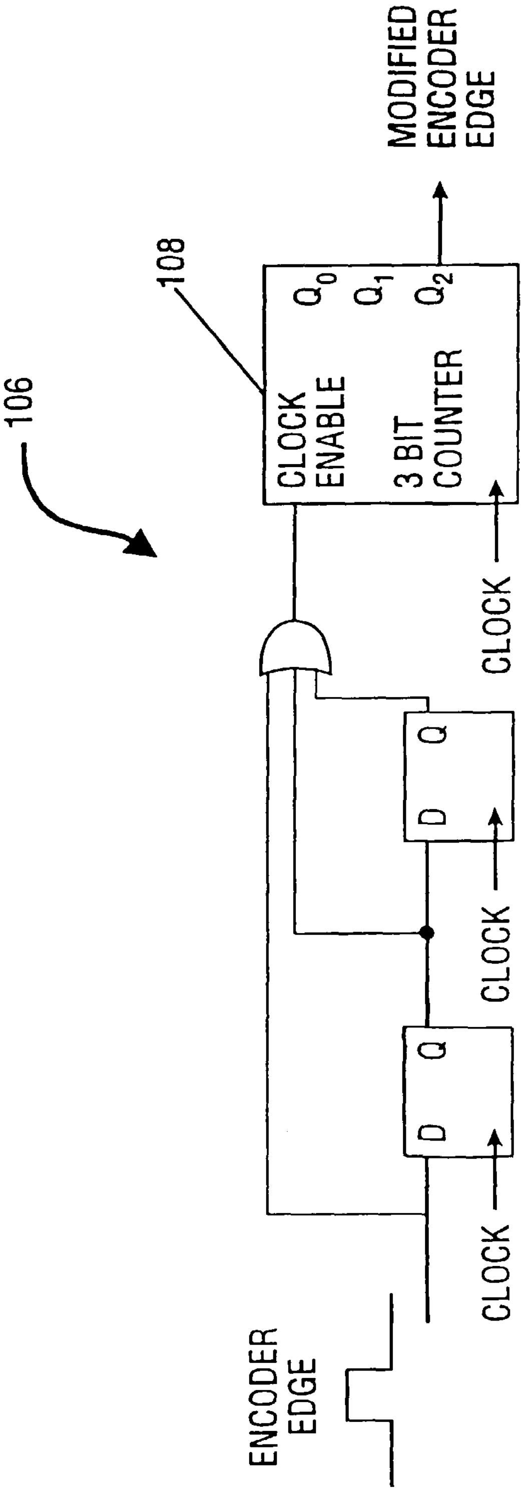
106
108
CLOCK ENABLE
3 BIT COUNTER
Q_0
Q_1
Q_2
MODIFIED ENCODER EDGE
ENCODER EDGE
CLOCK
D
Q
CLOCK
D
Q
CLOCK

FIG. 12

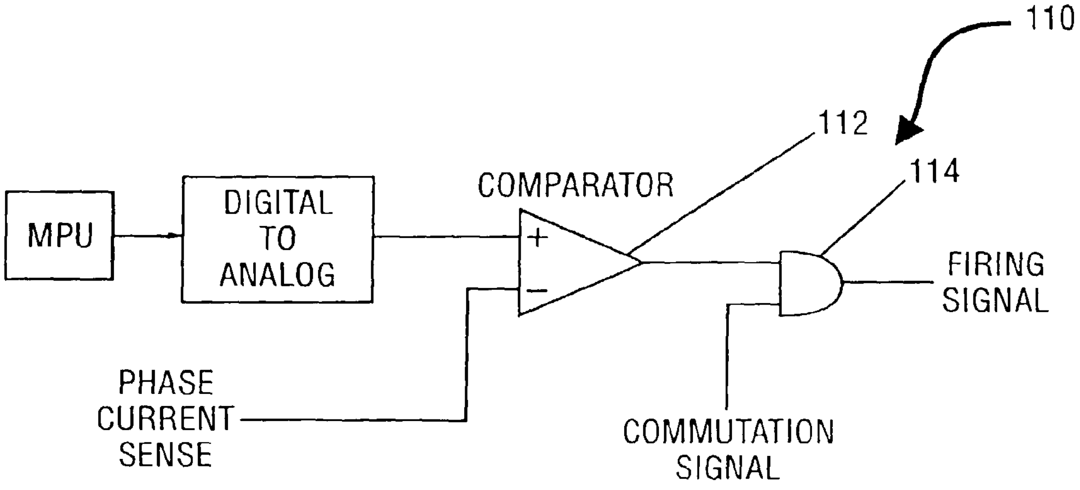
110
112
114
MPU
DIGITAL
TO
ANALOG
COMPARATOR
+
−
PHASE
CURRENT
SENSE
COMMUTATION
SIGNAL
FIRING
SIGNAL

FIG. 13